



Do we observe fluctuation of cross section in cosmic rays ?

GRZEGORZ WILK¹, ZBIGNIEW WŁODARCZYK²

¹The Andrzej Sołtan Institute for Nuclear Studies, Hoża 69, 00-681 Warsaw, Poland

²Institute of Physics, Jan Kochanowski University, Świętokrzyska 15, 25-406 Kielce, Poland
wilk@fuw.edu.pl

Abstract: It is known from some time that to explain some apparently *exotic events* observed in cosmic ray experiments, a deeply penetrating component in cosmic rays is needed, which, in turn, leads frequently to the nonexponential distributions of some observables. We argue that such unexpected behavior of some cosmic rays data can be most naturally explained by attributing them to the possible fluctuations of cross sections.

Keywords: The keywords will be used to select your subject from all ICRC contributions.

1 Introduction

Since quite a time already, a number of existing experimental results obtained by the Emulsion Chamber Experiments can be regarded as *exotic*. They were so far not encountered in the accelerator experiments and, notwithstanding developments in modern understanding of the elementary particle phenomena, they are remaining somehow forgotten and still wait for their proper understanding [1, 2, 3, 4]. Those are, for example, long flying components, centauro species or coplanar emission phenomenon. In what follows we shall very shortly remind properties of these chosen examples and we shall propose a common possible explanation: a possible fluctuation of the cross section remaining behind them in one or other way. Our aim is to bring ones attention to the fact that there is quite a number of unexplained phenomena in CR which still await their consideration, especially at present, with new experiments at LHC making contact with the CR experiments¹.

A word of justification in what concerns the use of notion of fluctuating cross section is in order here. It was introduced and discussed in [5, 6] (to describe results of some diffraction dissociation experiments on accelerators) and it was again invoked recently when discussing some Hera and Tevatron [7] or LHC [8] data. It means that this subject is still alive and worth of consideration. In CR it was used for the first time long time ago by us (cf. remarks below) [9]).

2 Some examples of *exotic events*

We shall now remind shortly the main features of the chosen *exotic events*. Only essential features will be presented, all details can be found in the references provided.

2.1 Long flying component (LFC)

This name was coined for the phenomenon observed when investigating the propagation of the initial flux of incoming nucleons [2, 3]. They can be presented in different ways but for the purpose of this presentation we shall concentrate only on the example of the distribution of the cascade starting points in thick lead chamber of the Pamir experiment [2]. What is regarded as peculiar, or even unexpected, is the fact that the commonly used exponential formula

$$\frac{dN}{dt} = f(t) = \frac{1}{\lambda} \exp\left(-\frac{t}{\lambda}\right) \quad (1)$$

is definitely invalid (especially at large depths t , $\lambda \sim 1/\sigma$ is the mean free path and σ is the corresponding cross section). The observed discrepancy look like hadrons tend to fly longer without interaction (therefore the term *long flying component* for this type of phenomenon). This was the place where we have used, for the first time in CR, the idea of fluctuating cross section [9]. It turns out that with the assumed variance of the cross section equal to ~ 0.2 one can nicely reproduce the observed enhanced tail of the distribution of the cascade starting points. It should be also stressed that the idea of fluctuations invoked here was prompted us, as explained below, towards applications of the so called Tsallis distribution (and, in general, Tsallis statistics) [10] to describe power-like behavior of many distributions observed both in CR [11] and in the usual multiparticle production phenomena [12].

1. One should keep always in mind that this can be really at most contact, not an overlap. The reason is that CR experiments probe the forward region of the phase space whereas accelerators are mostly concentrated in its central part.

2.2 Centauros

The other phenomena requiring a kind of deeply penetrating component are the so called *Centauro's* and *mini-Centauro's*. Their characteristic feature is the extreme imbalance between hadronic and gamma-ray components among the produced secondaries. Actually, they are the best known example of numerous unusual events reported in cosmic-ray experiments [4]. There are many attempts to explain them, like different types of isospin fluctuations or formation of disoriented chiral condensate (DCC) [13], multiparticle Bose-Einstein correlations (BEC) [14], strange quark matter (SQM) formation [15, 16]). All of them reproduce many features of Centauros in a single collision but fail to explain the substantial number of interactions contributing to the development of families observed at mountain altitudes among which Centauro were observed. Actually, it was shown that families recorded at mountain altitudes are insensitive to any isospin fluctuations [16, 17].

2.3 Coplanar emission

Phenomenon of alignment of structural objects of gamma-hadron families near a straight line in the plane at the target diagram was first observed during examination of multicore halos and, later, when observing distinguished energetic cores (i.e. halos, energetic hadrons, high energy gamma quanta or narrow particle groups) [18, 19, 20]. The excess of aligned families found in these cascades exceed any known conventional concept of interaction. Many attempts to interpret this phenomenon of coplanar emission were undertaken. For example, in [21] it was proposed to be due to the copious occurrence of semihard jets (with $p_t > 3$ GeV). However, such interpretation is not satisfactory because of the noticeable difference in the energy distribution of the main streams of secondaries (jet particles have too low energy). In [22] coplanar phenomena were attributed to the projection of the quark-gluon string ruptures produced in the process of semi-hard double inelastic diffraction dissociation (with string being inclined between a semi-hard scattered fast quark and the incident hadron remnants). This explanation seems plausible because the energy threshold of the alignment effect is consistent with the threshold-like dependence of semi-hard double inelastic diffraction. The length of aligned groups of EDC as a projection is also more or less in agreement with the transferred momentum while string production. In this case the target diagram of a superfamily with alignment may be considered as a direct photographic image of such. However, until now no truly satisfactory explanation exists, especially when realizing that the observed alignment occurs not so much in the elementary interaction but during the development of the full cascade, which is a macroscopic process with substantial number of interactions contributing to family formation. Also here the long-flying component with the mean free path of the order of the few hundreds of g/cm^2 is required [19].

3 Nonexponential behavior

The standard modelling used to analyze cosmic ray data assumes the constant cross section at given energy. However, since some time already the evidence is accumulating that such approach is too simplified because it does not account for the possible intrinsic fluctuations in cross section which result in a characteristic power-like behavior of the depth distribution of the starting points of cascades [11]. The origin of the cross-section fluctuations (CSF) can be traced down to the fact that hadrons have internal degrees of freedom (color-carrying quarks and gluons) and can therefore collide in different internal configurations resulting in different cross sections. Fluctuations of the hadronic cross sections are discussed in the literature and observed in diffraction dissociation experiments on accelerators [5, 6, 7, 8]. We refer for details and physical justification of this phenomenon to [5, 7].

Actually, as was shown in [23], such fluctuations inevitably lead to the so called Tsallis statistics [10], which in a natural way enlarges the predictive power of the usual statistical approaches. For completeness, we list some basic features of Tsallis statistics [10]. It is well known [23, 24, 25, 26, 12] that whenever in the exponential formula (1) the parameter $\lambda \propto 1/\sigma$ fluctuates according to gamma distribution,

$$g(1/\lambda) = \frac{1}{\Gamma\left(\frac{1}{q-1} - s\right)} \frac{\lambda_0}{q-1} \left(\frac{1}{q-1} \frac{\lambda_0}{\lambda}\right)^{\frac{1}{q-1} - 1 - s} \cdot \exp\left(\frac{1}{q-1} \frac{\lambda_0}{\lambda}\right) \quad (2)$$

one obtains as a result the power-like distribution

$$h_q(t) = \int_0^\infty f(t) g(1/\lambda) d(1/\lambda) = \frac{2-q}{\lambda_0} \left[1 - (1-q) \frac{t}{\lambda_0}\right]^{\frac{1}{1-q}}. \quad (3)$$

Here λ_0 denotes the value of λ around which one has fluctuations given by Eq. (2) and parameter s indicates to which classes of superstatistics (notion introduced in [27]), type A with $s = 0$ or type B with $s = 1$, this distribution belongs (we put $s = 0$ in all analysis of cosmic ray data). In both cases the so called nonextensivity parameter $q \in (1, 2)$ reflects the amount of fluctuations with

$$q = 1 + \frac{\omega}{1 + s \cdot \omega}, \quad \text{where} \quad \omega = \frac{\langle \lambda^2 \rangle - \langle \lambda \rangle^2}{\langle \lambda \rangle^2}. \quad (4)$$

Notice that for $q \rightarrow 1$ Eq. (3) becomes Eq. (1) used before. Available experimental data at low energies (up to 10^4 GeV in lab.) suggest that relative variance of cross section increase with energy as $\omega \sim \ln s$ or is asymptotically constant $\omega \sim b - c/s^\epsilon$ [5]. As mentioned above, in Ref. [9] distribution of depths of starting points of cascades in Pamir lead chamber was described by Monte Carlo simulation using the cross section sampled from the uniform

distribution,

$$\sigma \in [(1 - \sqrt{3\omega\sigma_0}), (1 + \sqrt{3\omega\sigma_0})],$$

with $\omega \simeq 0.2$. It was then proposed in [11] to resort to Tsallis distribution (3) (corresponding to fluctuations of the cross section according to the gamma distribution (2)) to describe the same Emulsion Chamber data and the relative fluctuations of cross section found there was $\omega \simeq 0.3$.

4 Concluding remarks

Apart of the above scenario (i.e., CSF) aiming to explain *long flying component*, the other hypothesis have been widely discussed in the literature [2, 3]:

- (i) charm particles (charmed Λ_c hyperons and D mesons) with $\sigma_{charm-Pb} < \sigma_{p-Pb}$ are produced somewhere in the upper parts of chamber;

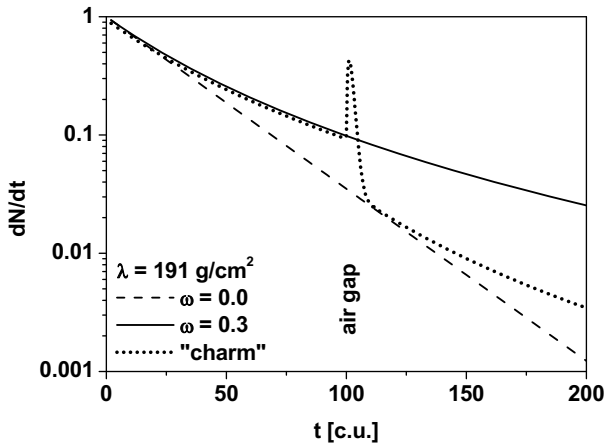


Figure 1: Schematic depth distribution of the starting points of cascades in the two-storey Pb chamber. The dotted line shows absorption curve in the case of production of charmed particles. Full line shows results for fluctuating cross section. The normal attenuation are shown by broken curve. All distributions are normalized to 1 at $t = 0$.

- (ii) there exist some new weakly absorbed hadrons not yet found in accelerators.

The weakness of the first hypothesis is that in order to explain the observed effect we need to assume that the production cross section of charmed particles is as high as $\sigma_{\Lambda_c, D} \simeq 2$ mb/nucleon, while extrapolation of accelerator data gives one order less value for $\sigma_{\Lambda_c, D}$. In order to check different hypothesis, a special experiment with two-storey emulsion chamber is currently running at the Pamir, however, so far there are no results available from it. The schematic view of expected results and its comparison to our proposition is shown in Fig.1. The most characteristic feature expected is the occurrence of a bump in the absorption curve. It is caused by the fact that the chamber has an

air gap (2.5 m) where an effective decay of charmed particles should take place. In the case of fluctuating cross section we observe nonexponential behavior in the whole chamber. The second hypothesis still awaits its possible future check.

References

- [1] Z.Włodarczyk: 1993, Proc. 23th ICRC Calgary (Invited, Rapporteur & Highlight Papers, p.355-382-27), Eds. D.A.Leahy et al., World Scientific, Singapore; G.Wilk, Z.Włodarczyk, Acta Phys. Polon. B, 1996, **27**: 2649-2656
- [2] S.A.Slavatinsky, AIP Conf. Proc., 1993, **276**: 3; A.S.Borison et al., Nucl. Phys. B (Proc. Suppl.), 2008, **175**: 143-148
- [3] V.I.Yakovlev, AIP Conf. Proc., 1993, **276**: 154-167
- [4] C.M.G.Lattes et al., Phys. Rep., 1980, **65**: 151-167; A.S.Borison et al., Phys. Lett. B, 1987, **190**: 226-233
- [5] S.Blattel et al., Phys.Rev. D, 1993, **47**: 2761-2772
- [6] H.Heiselberg et al., Phys. Rev. Lett., 1991, **67**: 2946-2469
- [7] L.Frankfurt et al., Phys. Rev. Lett., 2008, **101**: 202003
- [8] M.Strikman, Phys. Rev. D, 2011, **84**: 011501(R)
- [9] G.Wilk, Z.Włodarczyk, Phys. Rev. D, 1994, **50**: 2318-2320
- [10] C. Tsallis, J. Stat. Phys., 1988 **52**: 479-487; Braz. J. Phys., 1999 **29**: 1-35; Physica A, 2004, **340**: 1-10; *ibidem* 2004, **344**: 718-736 and references therein; for an updated bibliography on this subject see <http://tsallis.cat.cbpf.br/biblio.htm>.
- [11] G.Wilk, Z.Włodarczyk, Nucl. Phys. B (Proc.Suppl.), 1999, **A75**: 191-193
- [12] G. Wilk and Z. Włodarczyk, Eur. Phys. J. A, 2009, **40**: 299-312
- [13] R.Attallah, J.N.Capdeville, J. Phys. G, 1993 **19**: 1381-1392; J.D.Bjorken, Int. J. Mod. Phys. A, 1992, **7**: 4189-4257
- [14] S.Pratt, V.Zelevinsky, Phys. Rev. Lett., 1994, **72**: 816-819
- [15] J.D.Bjorken, L.D.McLerran, Phys. Rev. D, 1979, **20**: 2353-2379; A.D.Panagiotou et al., Phys. Rev. D, 1992 **45**: 3134-3142; M.N.Asprouli et al., Astropart. Phys., 1994, **2**: 167-174
- [16] G.Wilk, Z.Włodarczyk, Nucl. Phys. B (Proc.Suppl.), 1997, **52**: 215-217; Acta Phys. Polon. B, 2002, **33**, 277-295; Int. J. Mod. Phys. A, 2005, **20**: 6724-6726
- [17] G.Wilk, Z.Włodarczyk, J. Phys. G, 1993, **19**: 761-768
- [18] V.V. Kopenkin, A.K. Managadze, I.V. Rakobolskaya, T.M. Roganova, Phys. Rev. D, 1995, **52**: 2766-2774
- [19] A.S.Borison et al, Nucl. Phys. B (Proc. Suppl.), 2001, **97**: 118-121
- [20] T.Antoni et al, Phys. Rev. D, 2005, **71**: 072002; R.A.Mukhamedshin, Phys. Part. Nucl. Lett. , 2006, **3**: 234-240

- [21] F. Halzen, D. Morris, in Proceedings of the XXIth ICRC, Adelaide, Australia, 1989, ed. R.J. Protheroe (Graphic Services, Northfield, South Australia, 1990), Vol. 8, p. 18
- [22] I.I. Roizen, Mod. Phys. Lett. A, 1994, **9**: 3517-3522; A.D. Mironov, I.I. Roizen, Yad. Fiz. 1988, **48**: 194-196 [Sov. J. Nucl. Phys., 1988, **48**: 123-125]
- [23] G. Wilk and Z. Włodarczyk, Phys. Rev. Lett., 2000, **84**: 2770-2773; Chaos Solitons Fractals, 2001, **13** (3): 581-594
- [24] C. Beck, Phys. Rev. Lett., 2001, **87**: 180601
- [25] T.S. Biró, A. Jakovác, Phys. Rev. Lett., 2005, **94**: 132302
- [26] G. Wilk and Z. Włodarczyk, Physica A, 2007, **376**: 279-288
- [27] C. Beck, E.G.D. Cohen, Physica A, 2003, **322**: 267-275-224; F. Sattin, Eur. Phys. J. B, 2006, **49**: 219

